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16. ABSTRACT The paper discusses EPA/IERL-RTP R&D, underway since 1967, to advance combustion technology and the abatement and control of nitrogen oxides (NOx) and other combustion-generated pollutants from major stationary combustion sources. Although emphasis is given to R&D of new and improved methods for the prevention and control of air pollution resulting from the burning of fuels and for improving the efficiency of fuels combustion and of combustion systems overall, the program considers pollution control from a multimedia viewpoint. The primary air pollutants under consideration in the program, and for which control by combustion modification methods is feasible, are NOx, CO, hydrocarbons, carboraceous materials, particulates, and smoke. The development of improved technically feasible and cost-effective control methods will ensure the most efficient utilization of existing and available fossil fuels, especially coal, while simultaneously improving air quality. Technologies being developed and evaluated under this progam should lead to environmentally acceptable utilization of available fossil fuels in a wider range of applications and should help ease the energy situation by allowing more widespread use of available fuels. To facilitate technology transfer and most practically to communicate recent combustion research results, EPA organized a three-day "Symposium on Stationary Source Combustion" to address current concerns of those in the combustion field. The Symposium was held in Atlanta, Georgia, September 24 to 26, 1975.

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Combustion	Particulate	21B
Nitrogen Oxides		07B
Carbon Monoxide		
Hydrocarbons		07C
Dust		11G
Smoke		

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STATIONARY SOURCE COMBUSTION: AN R&D UPDATE

Robert E. Hall and **Joshua S. Bowen**
U.S. Environmental Protection Agency

The U. S. Environmental Protection Agency (EPA) is carrying forward a combustion research and development program which is the responsibility of the Combustion Research Branch of the Industrial Environmental Research Laboratory (IERL-RTP), located at Research Triangle Park, N. C. The aim of this program, which has been underway since 1967, is the advancement of combustion technology and the abatement and control of nitrogen oxides and other combustion-generated pollutants from major stationary combustion sources. Although emphasis is given to research and development of new and improved methods for the prevention and control of air pollution resulting from the burning of fuels and for improving the efficiency of fuels combustion and of combustion systems overall, the program considers pollution control from a multi-media viewpoint. The primary air pollutants under consideration in the program, and for which control by combustion modification methods is feasible, are nitrogen oxides, carbon monoxide, hydrocarbons, carbonaceous materials, particulates, and smoke. The development of improved technically feasible and cost-effective control methods will insure the most efficient utilization of existing and available fossil fuels, especially coal, while simultaneously providing improvement in air quality. Technologies being developed and evaluated under this program should lead to environmentally acceptable utilization of available fossil fuels in a wider range of applications and should help ease the energy situation by allowing more widespread use of available fuels. In order to facilitate technology transfer and most practically to communicate recent combustion research results, EPA organized a three-day "Symposium on Stationary Source Combustion" specifically designed to address current concerns of those in the combustion field. Arthur D. Little, Inc. acted as coordinator of the Symposium. The Symposium, attended by approximately 200 persons representing industry, government, and the academic community, was held at the Fairmont Colony Square Hotel in Atlanta, Ga., from September 24 to 26, 1975.

Dr. Bowen, Symposium Chairman, is Chief, EPA Combustion Research Section. Mr. Hall, Symposium Vice Chairman, is a research mechanical engineer for EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC 27711.

The Symposium on Stationary Source Combustion was primarily composed of project reviews of contracts, grants, and in-house programs of the Industrial Environmental Research Laboratory-RTP, and was divided into four sessions: field testing and survey activities, fuels research and development, process research and development, and fundamental combustion research. The studies discussed are directed to the optimization and application of practical combustion modifications which may be applied to a broad range of combustion sources to minimize the production of nitrogen oxides and other pollutants while simultaneously improving combustion efficiency. Among the techniques under study are low excess air operation, staged combustion, flue gas recirculation, and improved burner and system designs. The combustion characteristics of alternate new fuels which may become available in the future are also investigated as well as advanced combustion concepts. Many of these techniques have the effect of reducing the peak flame temperatures and/or reducing the amount of oxygen available for reaction in the early stages of combustion, both being conditions which result in the formation of less nitrogen oxides.

Although the major portion of the program is conducted under contract with various industrial and university research groups, a significant number of tasks are performed in the in-house laboratory. This in-house work of an exploratory and verificative nature investigates the feasibility of new concepts and devices, and provides the necessary in-house engineering expertise to guide and direct the individual contracts and overall program and to promote acceptance of EPA's efforts by industry. The in-house projects are performed on a variety of systems, including versatile experimental furnaces, commercial boilers and heating units, and diesel and gas turbine engines, which are fully equipped with controls and instruments to permit careful measurement of the effects of changes in hardware and operating conditions on the combustion efficiency and emissions characteristics.

The results of this program in the form of reports, and design and guideline manuals, provide information for manufacturers and users which will aid them in producing and operating combustion equipment in a manner that will be acceptable from an environmental and energy conservation point of view. The information will also be of benefit to environmental planners and federal, state, and local standards setting and regulatory groups since it provides data on the performance of equipment and the levels of control of the pollutants under consideration when optimum combustion control methods are applied.

The following series of reports represent a mini-glimpse of the Symposium. A more comprehensive compilation will be published in the Symposium Proceedings.

The Symposium was opened with a Welcoming Address by Dr. J. K. Burchard, Director of IERL-RTP. The Keynote Speaker was Mr. F. Princiotta of EPA's Office of Energy, Minerals, and Industry in Washington, D. C. In the keynote address Mr. Princiotta explained the EPA research and development organization and described the status of EPA's NO_x emission control strategy and the role of the EPA-sponsored stationary source combustion efforts in providing for control technology development and assessment.

Session I—Fundamental Research

Ten papers covering both experimental and modeling studies of various aspects of pollutant formation and reaction during combustion were presented at this session. J. D. Bittner, of the Massachusetts Institute of Technology, started the session with his discussion of the "*Formation of Soot and Polycyclic Aromatic Hydrocarbons in Combustion Systems.*" The study was performed with a low pressure laminar flat premixed flame to determine the effect of NO_x control techniques on PCAH and soot emissions. It has been found that soot emissions increase as atomizing air pressure decreases.

"*Effects of Fuel Sulfur on Nitrogen Oxide Emissions,*" by Dr. J. O. L. Wendt of the University of Arizona, described laboratory experiments in which a methane-air flat flame was doped with SO_2 or H_2S. The test results showed conclusively that fuel sulfur inhibits the formation of NO_x arising from thermal fixation of nitrogen in the combustion air.

"*Two Dimensional Combustor Modeling*" was the title of a paper presented by R. C. Buggeln of United Technologies Research Center. In his presentation Mr. Buggeln reviewed the status of numerical methods of predicting the coupled fluid mechanics and chemistry occurring within combustion devices. He presented results showing comparisons between predictions and measured values of combustion data for several swirling and non-swirling flow systems.

Dr. C. T. Bowman of United Technologies Research Center discussed the "*Effects of Interaction between Fluid Dynamics and Chemistry on Pollutant Formation in Combustion.*" This paper presented the results of an experimental investigation which was carried out using an axisymmetric combustor in which a central gaseous fuel stream mixes with a coaxial annular air stream. The author stated that aerodynamic flame stabilization, achieved without benefit of swirl or physical flameholders in systems having large air-fuel momentum flux ratios, produces strong stirring which results in reduced temperatures and in relatively low NO formation and hydrocarbon consumption rates.

A paper on the "*Fate of Coal Nitrogen During Pyrolysis and Oxidation*" by J. H. Pohl of the Massachusetts Institute of Technology, reported results of an experimental investigation to determine factors influencing fuel nitrogen conversion. Using a laboratory drop tube furnace, experiments were designed to study the devolatilization and oxidation of coal in order to determine whether fuel nitrogen conversion occurs by oxidation of nitrogen compounds devolatilized from the coal or by oxidation of nitrogen in the char. Mr. Pohl reported results showing that nitrogen retention in the char decreased with increasing temperature. He also discussed the fate of nitrogen devolatilized in inert atmospheres, and the effect of fuel equivalence ratios on the oxidation of fuel nitrogen.

Dr. V. S. Engleman of Exxon Research and Engineering Company presented "*A Detailed Approach to the Chemistry of Methane/Air Combustion: Critical Survey of Rates and Applications.*" This paper identified and discussed in detail the basic steps in the approach to modeling of combustion processes as (1) selection of species, (2) construction of reactions, (3) evaluation of probable relative importance, (4) survey of kinetics data, and (5) evaluation and selection of rates. The author pointed out that the detailed approach as applied to the chemistry of methane-air combustion is useful for guidance in establishing the reaction mechanisms, the evaluation of competitive reactions, establishing global behavior, and identifying critical reactions. However, he cautioned that in application of the approach special attention should be paid to avoid the pitfalls of inclusion of insufficient species, overelimination of reactions, overreliance on uncertain rate constants, and construction of minimum sets which are actually quasidetailed mechanisms.

An experimental and analytical program, conducted by the Rocketdyne Division of Rockwell International, to investigate the chemical and physical processes involved in the conversion of fuel-bound nitrogen to NO_x during com-

bustion was the subject of a paper, entitled *"Chemical Reactions in the Conversion of Fuel Nitrogen to NO_x,"* was presented by A. E. Axworthy. Based on pyrolysis studies of model fuel-nitrogen compounds, of fuel oils, and of coals, the study showed that HCN and, to a lesser extent, NH_3, are likely to form from nitrogen compounds in the preflame stages of combustion. Further studies in a premixed flat-flame burner investigated the combustion kinetics involved in the conversion of HCN and NH_3 to NO and N_2 in rich and lean CH_4-O_2-Ar flames. The burner studies showed that most HCN survives the luminous zone of lean or rich flames. For lean flames, it was reported that NO forms rapidly just above the luminous zone from a reaction intermediate. The major conclusion is that the formation of NO from NH_3 and HCN is a relatively slow process even under fuel-lean conditions where the NO yields are high.

In the paper entitled, *"Prediction of Premixed Laminar Flat Flame Kinetics, including the Effects of Diffusion,"* presented by Dr. R. M. Kendall of Aerotherm-Acurex Corporation, the PRemixed One-dimensional Flame (PROF) computer code and its application were described. The PROF code has been developed to provide for comprehensive theoretical treatment of the interaction of the complex chemical and physical processes responsible for pollutant formation during combustion. The code provides for the application of multivariable boundary value problem solution procedures, including a general chemical kinetics formation and the unequal diffusion of all species. Initial flame system calculations, with up to 42 kinetic reactions and 19 species, have demonstrated the speed, reliability, and accuracy of the PROF code in predicting complex combustion and pollutant formation chemistry.

Dr. R. Shaw reported on work at Stanford Research Institute on the *"Estimation of Rate Constants."* Estimates have been made of the chemical reaction rate constants between the temperatures of 300 and 3000 Kelvin for all possible transfer reactions of atoms and diatomic species containing the elements carbon, hydrogen, oxygen, nitrogen, and sulfur. These estimates are being used primarily in mathematical models of combustion processes to predict combustion and pollution formation chemistry.

Dr. C. England of NASA's Jet Propulsion Laboratory presented results of his investigations on the *"Role of Flame Interactions in Pollutant Formation."* The objective of his studies has been to establish the influence of burner-to-burner interactions on NO_x formed in gas and oil flames. An experimental combustion system comprised of a number of separate fuel injectors has been used to simulate the burner arrays in large multi-burner boilers. It is found generally that the emissions are dominated by turbulent mixing phenomena which tend to homogenize the gases and prevent effective NO_x control. Wide burner spacing and good heat removal near the base of the burners are recommended for low NO_x operation.

Panel Discussions

Concurrent panel discussions were scheduled following Session I near the end of the first day's agenda. One of the panels addressed the subject of *"Combustion Chemistry and Modeling"* while the other discussed *"Federal, Regional, State and Local Air Pollution Regulations."* In the panel discussions experts reviewed the current state of activity in their fields to provide an overview of the area.

The panel on *"Combustion Chemistry and Modeling"* was represented by two distinguished contributors in the combustion field. Dr. A. F. Sarofim, a Professor of Chemical Engineering at MIT, presented *"Combustion Chemistry,"* in which he reviewed the current understanding of mechanisms and kinetics of reactions pertinent to the combustion of fossil fuels, with special emphasis given to those reactions leading to pollutant formation. Dr. T. J. Tyson, Director of the Environmental and Applied Sciences Division of Ultrasystems, Inc., discussed the subject, *"Combustion Kinetics Modeling and Aerodynamic Modeling."* He presented detailed coverage of the state of the art of the separate components making up a total model of the combustion process and the method of integrating these components. The models being developed for prediction of pollutant emissions in combustion systems involve the complex interaction of heat transfer, mass transfer, heat relief, and species production, all of which were considered by Dr. Tyson.

The views on *"Federal, Regional, State and Local Air Pollution Regulations,"* the subject of the second panel, were presented by four experts in the area of air pollution regulations. S. T. Cuffe, Chief of the Industrial Studies Branch of EPA's Emission Standards and Engineering Division, addressing the federal role, summarized the procedures that EPA follows in the development of performance standards. He also discussed the standards which may be developed over the next several years and identified some of the concerns and problem areas encountered. G. T. Helms, the Deputy Director of the Air and Hazardous Materials Division in EPA's Region IV office in Atlanta, presented the regional viewpoint. He reviewed the current air pollution regulations that apply throughout the southeastern United States and highlighted changes which have ensued due to the energy crisis. R. H. Collom, Jr., Chief, Air Protection Branch, Environmental Protection Division, Department of Natural Resources of the State of Georgia discussed the state's air pollution regulations. He outlined the types of equipment now being examined by Georgia's Environmental Protection Division, the research programs with which his staff is involved, and the coordination of efforts between federal, regional, state, and local agencies. Mr. T. T. Kason, Deputy Commissioner of the Department of Environmental Control of the City of Chicago, represented the local level. His presentation focussed on the means that Chicago is using to meet federal standards for pollution control through its local agency and provided information on how the agency communicates and coordinates its activities with federal, regional, state, and other local agencies.

Session II—Fuels Research and Development

G. B. Martin of EPA's Combustion Research Branch presented the paper *"Assessment of Combustion and Emission Characteristics of Methanol and Other Alternate Fuels,"* in which he described EPA in-house studies involving the combustion of alcohols as low emission fuels. Although emphasis was placed on the results for the alcohol fuels, methanol and isopropanol, burned separately and in emulsions with distillate oil, results were also given for mixtures of the two alcohols. Emission levels and combustion characteristics of these fuels were discussed in comparison to those of conventional clean fuels.

Dr. D. R. Shoffstall of the Institute of Gas Technology presented a paper on *"Burner Design Criteria for Control of Pollutant Emissions from Natural Gas Flames."* This paper reported on an experimental program which was conducted to determine the importance of burner design and operating conditions, and furnace geometry on the total level of NO_x emissions from a gas-fired pilot scale furnace. The results of this study have led to a number of design criteria which were applied in the development of a low NO_x (LNO) emission burner. This LNO burner is capable of maintaining flame characteristics similar to those of a burner currently being used in industry while producing 60% less NO_x.

Mr. L. P. Combs of the Rocketdyne Division, Rockwell

International, discussed analytical and experimental investigations of an *"Integrated Low-Emission Residential Furnace."* The objectives of this work are simultaneously to minimize pollutant emissions and improve fuel economy for oil-fired residential space heating furnaces. The approach has involved research on design of conventional pressure-atomizing oil burners for low emissions, matching furnace fireboxes to such low emission burners, and operating these optimized components under fuel conservation conditions. The prototype of a warm air furnace system will be built for further study, and the results obtained should lead to the final design of a cost competitive, commercially producible warm-air furnace of improved low emission and efficiency characteristics.

"The Control of Pollutant Emissions from Oil Fired Package Boilers" was the subject of a paper presented by Dr. M. P. Heap of Ultrasystems, Inc. The objective of this project, which was performed in part by the Foster Wheeler Energy Corporation, was to provide information on the control of nitrogen oxide emissions from package boilers by the use of flue gas recirculation or staged combustion techniques. The speaker pointed out that oil atomization parameters not only have a strong influence upon uncontrolled emissions but also influence the effectiveness of staged combustion as a control technique. It was found that pollutant formation in confined oil flames is strongly dependent upon the distribution of axial and tangential velocity at the burner throat. The field tests have demonstrated that 50% reduction in NO_x emissions from firetube boilers is possible without incurring serious penalties due to emissions of other pollutants. 30% reduction in NO_x emissions from a firetube boiler firing oil containing nitrogen can be obtained by flue gas recirculation. Reductions in watertube boilers appear to be strongly dependent upon combustion intensity.

A newly initiated research investigation of catalytic combustion was reported by J. P. Kesselring of Aerotherm/Acurex Corporation in a paper entitled, *"Pilot Scale Investigation of Catalytic Combustion Concepts for Industrial and Residential Applications."* The use of catalysts in place of conventional burners for promoting hydrocarbon reactions appears to have advantages in the control of emissions. The research reported here addresses the basic lack of knowledge concerning catalyst characteristics, wash coat, support, and bed depth required for an oxidation reaction to proceed to completion. The program will investigate system techniques such as bed cooling, exhaust gas recirculation, and staged combustion to hold the bed temperature down.

Dr. Heap made a second presentation, entitled *"The Optimization of Burner Design to Reduce NO_x Emissions from Pulverized Coal and Residual Oil Flames."* This paper reported the status of a project for development of low emission coal burner scale-up criteria. Earlier small scale single burner experiments, performed at the International Flame Research Foundation, have shown that mixing processes dominate the emission of NO_x from turbulent diffusion flames. The current project has as its goal an optimized full scale burner design providing fuel-air mixing patterns necessary to insure minimum pollutant emissions while satisfying other combustion requirements.

R. A. Brown of Aerotherm/Acurex Corporation discussed the *"Pilot Scale Investigation of Combustion Modification Techniques for NO_x Control in Industrial and Utility Boilers."* The paper described the features and capabilities of a versatile research test furnace facility and the tentative test plans to investigate specific aspects of NO_x combustion modifications. The furnace, capable of firing gas, oil, and coal at 3×10^6 Btu/hr (3.2 GJ/hr), provides a fairly realistic modeling of the geometry and aerodynamics of large multi-burner boilers. It can simulate essentially all combustion modifications for NO_x control. A test program has been planned, emphasizing initially R&D work with conventional fossil fuels and later with mixed and non-conventional fuels.

A special feature of the Symposium was a colorful and informative presentation by the Guest Speaker Dr. R. B. Rosenberg, entitled, *"Looking Ahead at Alternative Energy Sources."* Dr. Rosenberg is the Vice President of Engineering Research for the Institute of Gas Technology. His skillfully illustrated discussion addressed many of the important considerations related to finding timely and acceptable solutions to provide for the United States' future energy requirements. The major thrust of Dr. Rosenberg's remarks was that the United States needs a viable energy program and should move ahead with urgency in developing its available energy resources.

Session III—Process Research and Development

"Evaluation of the Effectiveness of Fuel Additives in Reducing Pollutant Emissions" was presented by R. D. Giammar of Battelle Columbus Laboratories. In this study the effectiveness of proprietary additives and pure compounds in reducing particulate emissions was evaluated in a 50 hp (50 kW) oil-fired packaged boiler. It was observed that additives containing certain alkaline-earth and transition metals in concentrations ranging from 20 to 50 ppm in the oil were effective in reducing carbon particulate by as much as 90%. These additives were also observed to be effective in reducing smoke and polycyclic organic matter (POM).

"Pollutant Formation and Furnace Design in Low Btu Gas Boilers" was presented by Dr. M. P. Heap of Ultrasystems. He reported test results of two combined cycle systems which appear to provide optimum conversion efficiency for coal-derived fuel gas to electric power.

A series of presentations related to utility boiler tests was begun by A. P. Selker of Combustion Engineering whose paper was entitled, *"Overfire Air as an NO_x Control Technique for Tangential Coal-Fired Boilers."* He described test results of a 125 MW utility boiler modified to include an overfire air system. The study showed that NO_x reductions of 20 to 30% were obtained with 15 to 20% overfire air when operating at an overall excess air level of 15 to 20% as measured at the economizer outlet. It was also concluded that incorporation of an overfire air system on tangential boilers will generally not significantly affect unit performance. The cost of installing an overfire air system on an existing unit could range from 2 to 4 times the cost for inclusion on a new unit design. Based on March, 1975 estimates existing unit modification cost could range from 0.2 to 1.5 $/kW, depending on unit size.

In the next presentation Dr. G. A. Hollinden of TVA discussed *"Control of NO_x Formation in Wall Coal-Fired Boilers."* In the TVA study overfire air ports were not available so burners in the top row were taken out of service and used for air injection only, to simulate overfire air ports. The tests confirmed previous tests by others in which NO_x emissions were reduced by 30 to 50% depending upon load and burner configuration. However, on this boiler TVA found that preliminary data indicate a significant increase in carbon loss and increased water tube wall corrosion rates on the side wall. This statement was clarified by adding that more data will be obtained to further quantify this finding.

Session IV—Field Testing and Surveys

The same topic was further discussed by A. R. Crawford and E. H. Manny of Exxon Research & Engineering when they presented *"The Effect of Combustion Modification on Pollutants and Equipment Performance of Power Gen-*

eration Equipment." They have found that a boiler equipped with the new Babcock & Wilcox dual register pulverized coal burners emitted 35% less NO_x under normal firing than was emitted from an identical boiler equipped with conventional burners. In other tests, tangentially fired boilers equipped with overfire air ports emitted about 20% less NO_x than similar boilers tested under normal operation. When a combination of overfire air ports and low excess air firing was used, a total NO_x reduction of over 50% was achieved. Only relatively minor differences were observed in particulate mass loadings and unburned carbon in the fly ash under "low NO_x" firing conditions. Measurement of corrosion rates were made on wall and tangentially fired boilers with specially designed corrosion probes. They showed no major or significant differences for "low NO_x" firing compared to normal operation. This was clarified by emphasizing that long term tests measuring actual furnace tube wall wastage are needed to confirm this finding.

"Analysis of Gas-, Oil-, and Coal-Fired Utility Boiler Test Data" was presented by O. W. Dykema of The Aerospace Corp. He discussed a semi-empirical analytical tool that was developed to guide NO_x control modifications in full scale multi-burner utility boilers. An approximate NO_x emission prediction equation was developed from a model and improved by regression analysis of data from over 600 tests on 16 operating boilers of the single and opposed wall, and tangential firing configurations. Parametric analysis with the resulting equation showed the effect of eight major variables affecting NO_x emissions.

Next, G. A. Cato of KVB, Inc. made a presentation entitled *"Influence of Combustion Modifications on Pollutant Emissions from Industrial Boilers."* The first year of the field test program was concerned with selecting a representative sample of 47 industrial boilers firing gas, oil, and coal and measuring their emissions during normal operation and with minor changes in operating variables. During the second year extensive combustion modification techniques including staged combustion and flue gas recirculation were used to determine the effect on emissions and efficiency. The combustion modification methods that have been successful in reducing NO_x from utility boilers are also effective with industrial boilers. NO_x reductions of 30 to 50% were achieved but this was accompanied by an increase in particulate ranging from 5 to 50% in some cases. In most cases efficiency was not degraded.

"Emission Characteristics of Small Gas Turbine Engines" was presented by J. H. Wasser of EPA. His paper presented emission characteristics of a 305 hp Solar Spartan gas turbine engine under baseline conditions and with water addition by firing a water-in-oil emulsion. The major air pollution problems for small gas turbines are the CO, unburned hydrocarbons, and fine particulate emissions. NO_x emissions were significant but diluted by the high levels of excess air. Use of emulsions did not benefit the emissions problem. Even though NO_x was reduced by 33% with 26% water in the emulsion, the CO level increased significantly. The addition of water had no effect on thermal efficiency. It was concluded that combustor redesign is necessary for major reductions of carbonaceous pollutants.

R. D. Giammar of Battelle presented *"POM and Particulate Emissions from Small Commercial Stoker-Fired Boilers."* The program consists of: (1) a survey to identify processes for manufacturing smokeless coal and to evaluate the suitability of these fuels for stoker-firing; (2) a survey to identify the manufacturers and designs of small stokers currently being marketed; and (3) an experimental laboratory program to measure emissions while firing a 20 hp stoker with several candidate fuels. The experimental portion of the program is currently being conducted, thus data are not available for analysis.

"Use of Western Coals in Small and Intermediate Sized Boilers" was discussed by Dr. K. L. Maloney of KVB, Inc. He discussed a program whose purpose is to assess the cost effectiveness of the use of lower sulfur Western coals as a means of reducing SO_x emissions from industrial sized boilers. The work will include an assessment of emission and air quality changes.

The final presentation was entitled *"Emission Control and Combustion Equipment Data in Industrial Process Heating"* by P. Ketels of the Institute of Gas Technology. The paper presented results of the study of several energy-intensive industrial processes, including the examination of equipment in use and operating practices, to assess the potential for simultaneous reduction in energy consumption and air pollution emissions.

Conclusion

In conclusion, the Symposium was successful since it provided a good review of EPA's in-house and contracted studies related to combustion research and development with stationary sources. There was a very worthwhile exchange of information among the attendees who included representatives from industry, government, and the academic community.

The fundamental research has provided very useful information about chemical reactions in the conversion of fuel nitrogen to NO_x, the role of flame interactions in pollutant formation, interactions between fluid dynamics and chemistry in pollutant formation, prediction of the kinetics of premixed laminar flat flames, the estimation of rate constants, the formation of soot and polycyclic aromatic hydrocarbons during combustion, and the effect of fuel sulfur on NO_x emissions. Fuels research and development has provided much information related to burner design for gas, oil, and coal fuels. Also, the papers discussing catalytic combustion concepts and emission characteristics of alternate fuels such as alcohols and water-in-oil emulsions were of much interest.

Cost and design information for application of NO_x control technology to classical combustion systems were provided in work related to process research and development and field testing. Results of modifications using overfire air ports and staged combustion as a successful means of controlling NO_x were reported. The detailed analysis of the utility boiler test data provided some interesting insights which may be helpful with new boiler designs. The variation of results of corrosion measurement on different coal-fired boiler designs strongly indicates a need for more detailed corrosion measurement for periods of 6 to 12 months. Because of their future potential, the presentations about pollutant formation and furnace design in low Btu gas fired boilers and the effectiveness of fuel additives as a means of reducing pollutant emissions were of much interest.

Field tests of industrial boilers with gas, oil, and a wide range of coal types with normal and modified combustion has much practical significance as does the on going study with small stoker fired coal burning boilers. The assessment of emission characteristics of small gas turbine engines indicates that basic design changes are necessary for significant reductions of pollutant emissions from that source. Also, the survey findings on industrial process combustion equipment will be used for planning a future field test study of industrial process equipment.

Many of the results reported are quite informative and show that progress is being made toward pollution abatement without adversely affecting equipment performance and efficiency. Some studies have raised new questions, and others appear to be in conflict or say different things. There are many areas where the information presented will be carefully considered in planning future combustion research and development programs.